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DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR ASSESSING ALTERNATIVE AGRICULTURE LAND USES: A CASE STUDY OF THE STELLENBOSCH WINE REGION

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ABSTRACT

The wine industry is accountable for 1.2 percent of the South African GDP. Financial margins of Stellenbosch wine estates have begun to shrink due to factors such as high production costs and increased competition. To be economically sustainable wine estates need to rethink their current business strategy and consider adopting a diversification strategy. This article identifies a holistic set of considerations that decision-makers in this industry need to evaluate when considering pursuing land use alternatives. It also considers how these factors can be used to develop a decision support system (DSS) to guide farmers through the decision-making process.

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1. INTRODUCTION

According to Wines of South Africa [2] the South African wine industry dates back to 1655, when the first vine was planted. Marais [3] states that this makes it one of the oldest wine industries in the world apart from Europe and the Mediterranean. In 2016, there existed over 3200 farmers that cultivate 98 597 hectares of vineyard in South Africa [4]. The term wine farm (often referred to as a winery outside of South Africa) refers to a place where grapes are grown, fermented, blended and the wine that is produced from the grapes is bottled [5]. The South African wine industry contributes to the country's GDP and provides job opportunities. The wine industry is one of the biggest agriculture exporters and was responsible for 1.2% of the national GDP [1]. The wine industry, including wine tourism, supported 300 000 jobs (direct and indirect employment) and contributed R36.1 billion to the economy in 2013 [1]. Of the total contribution of R36.1 billion to the GDP, almost R20 billion (53%) was created in the Western Cape. By volume South Africa is the eighth-largest national wine producer in the world [1].

Operating a successful wine business encompasses the anticipation of trends, possible opportunities and apprehensions within the industry, as well as taking into account the views of peers [6]. Constant improvements, and thus changes to a current business strategy are of the utmost importance to keep up with the latest trends and to ensure economic sustainability and revenue growth of wine estates.

Most of South Africa's water sources are under strain and South Africa is accordingly categorised as a dry country [7]. From 2016, the Western Cape had been gripped by a prolonged drought, resulting in the implementation of water restrictions as of 1 November 2016. The Western Cape, facing its worst water shortage in 113 years, was consequently declared a drought disaster zone in May 2017 [8]. The growing pressure on profitability margins of the South African wine industry [1] together with the drought requires wine estates to re-evaluate their business strategies. Many wine estates have recently been investigating diversification opportunities. However, many farmers have limited knowledge and experience outside of the wine industry, making the consideration of alternatives more complex. Thus, there exists an opportunity to develop a decision support system (DSS) that will regard a set of considerations to provide farmers with support when they are assessing possible land use alternatives. Consequently, this study develops a DSS to support farmers who are seeking to adopt a diversification business strategy and are therefore looking for a set of considerations that they need to evaluate when considering an alternative land use option.

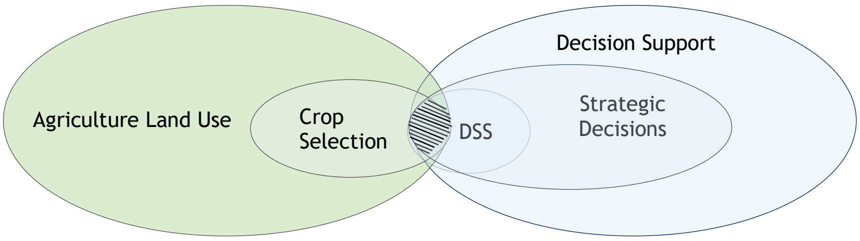


Figure 1: Research Domain

This research aims to identify and validate considerations to be used in the development of a DSS capable of assessing available land use alternatives in the Stellenbosch region to ensure financial success and economic sustainability.

2. METHODOLOGY

To solve the specified problem at hand, a literature study was done which defines strategic decision-making and determines whether decision support tools are applicable in the agriculture field. Specifically, literature was reviewed to determine the different DSSs that can be applied in the agriculture sector. Key considerations and DSS design requirements were considered before developing a novel DSS. The proposed DSS, which allows an end-user to provide tailored inputs for each of the identified considerations, evaluates and compares different selected land use alternatives with each other. After which an illustrative case study was utilised in order to evaluate the proposed DSS. The functionality and the considerations of the DSS were subsequently validated.

Five key stages of the methodology can be identified. These are shown and grouped according to different colours in Figure 2. According to those key stages, the study context is first outlined, after which an extensive literature review is conducted in order to identify and establish areas of importance within the relevant study fields. The information that is obtained from the literature review is subsequently used to inductively define considerations and design requirements by integrating the considerations and design requirements reflecting in existing decision support systems (DSSs). This enable the design of the best practice DSS. The fourth stage includes conducting research to provide context to the illustrative case study as well as using the illustrative case study to apply the developed DSS. Validating the proposed DSS, initially through doing an internal validation, and secondly by having interviews with experts and getting additional inputs from these experts by means of interview questionnaires concluded the fourth stage. The validation process included the research that gave context to the case study and the illustrative case study itself. These two parts as well as the validation of the DSS and the set of considerations were grouped together into one stage.

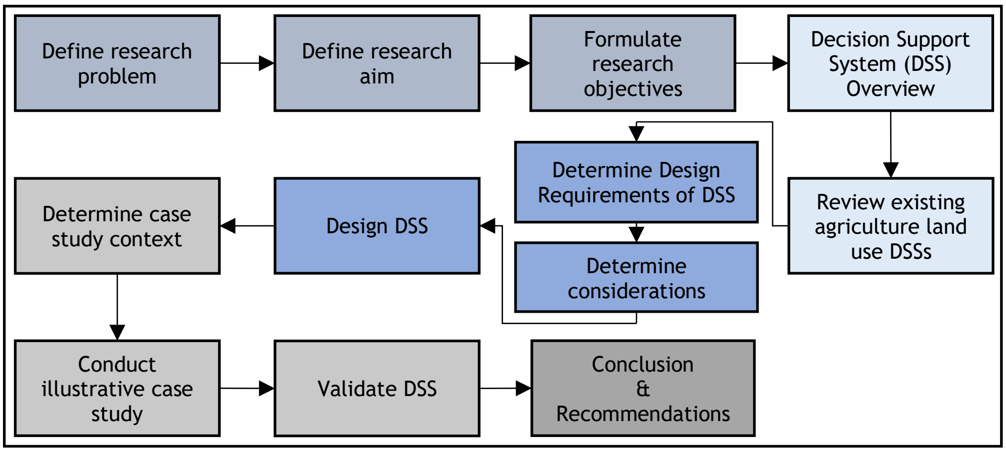


Figure 2: Research Process Flow Diagram

3. DECISION-MAKING SYSTEMS IN GENERAL AND IN AGRICULTURE

This section provides an overview of the literature pertaining to DSSs and the use of DSSs in the agricultural industry.

3.1 Decision Support Systems

Research conducted over the past two centuries has shown that humans assess information in a way that is far from rational [10]. Thus, a set of processes and analytical tools that support systematic and structural thinking especially when it involves difficult choices are involved or required. This set of processes and analytical tools, which are referred to as decision analysis, provides a method where a decision problem can be formed by separating the uncertainties, determining the subjective beliefs of the participants regarding those uncertainties, and then finally building a quantitative decision model [10].

Turban & Aronson [11] defines a DSSs as an 'interactive, computer-based systems, which help decision makers use data and models to solve unstructured problems'. DSSs support the analysis of current statuses or they can give future predictions, or both [12]. They can furthermore assist discussions, store data and models, stimulate learning, and advance internal capacity building [12].

More effective decisions can be made by using DSSs, by leading the user through specific decision stages and portraying the different possible outcomes from various alternatives. Farmers and farm managers can use these tools to efficiently facilitate farm management, by assessing different alternatives based on evidence [13]. Different crop management options and crops must be selected by farmers, which then allocate them to a specific field. These selections are critical, because they influence the productivity and short- and long-term profitability of the farm [14].

Jakeman, Letcher, & Norton [16] suggested an iterative process that consists of ten steps to develop and evaluate a DSS. They proposed certain general steps to ensure credible results and knowledge acquisition for the model, as well as for the community. The authors argue that some of their ten steps might involve the end user as well as the modeller.

Trust in the outcomes of the tool is another important aspect of a DSS that should be included according to [15]. McNie [17] refers to credibility as information that is accurate, valid and of high quality, as a consideration for useful information. Trust in the outcome of the DSS as well as the accuracy, validity, and quality of the information is incorporated into the DSS by consulting decision makers in the agriculture sector, thus validating the model.

3.2 DSSs in Agriculture

A need has been established for a DSS to provide help to farmers considering an agricultural diversification strategy. Especially some who want to evaluate possible land use alternatives that they can employ to stay viable. To support this current literature was reviewed to determine which agricultural focussed DSSs already exist. Table 1 provides an overview of only the leading agriculturally focussed DSSs found. This illustrates DSSs developed for crop selection, and the theory/work a particular DSS is based on.

Hartati & Sitanggang [18] argue that it is not only preferable to apply a DSS for efficient land suitability evaluation and crop selection problems, but also important. Moreover, the DSS assists the decision makers in comprehending the decision problem as well as the effect that their choices have on the enterprise, by allowing them to continuously exchange information between the system and themselves [19 - 21]. The complexity of these systems varies greatly.

Table 1: Decision Support Systems (DSSs) for crop selection

Author/Source	Based on	Focus area	Consideration
Radelescu & Radelescu [30]	Portfolio Theory	Financial risk	↓ Climate risk ↓ Market risk
Collender [31]	Mean variance analysis	Risk estimation	Mean variance characteristics
Salleh [32]	Fuzzy Modelling	Crop selection	Uncertainties during the development of the agriculture DSSs
Hartati & Sitanggang [18]	Fuzzy Modelling	Evaluate land suitability	Land characteristics
Balezentiene, Streimikiene, & Balezentis [33]	Fuzzy MULTIMOORA method	Sustainable energy	Climatic suitability, ↓ Environmental pressure
Nevo & Amir [34]	Rule-based expert system	Crop suitability	Severe uncertainties
Rossing, Jansma, De Ruijter, & Schans [23] van Ittersum, Rabbinge, & van Latesteijn [26] Makowski, Hendrix, van Ittersum, & Rossing [35] Ten Berge et al. [36] Dogliotti, Van Ittersum, & Rossing [37]	Multi goal linear programming	Soil	↓ Erosion, ↑ Organic matter ↑ Rate of change
Annetts & Audsley [23]; Dogliotti, Van Ittersum, & Rossing [38]; Bartolini, Bazzani, Gallerani, Raggi, & Viaggi [39]; Sarker & Ray [40]; Louhichi et al. [41]	Multi-objective optimization problems Process-based simulation model Empirical data	Profit	↑ Gross margin ↑ Annual profit ↑ Income ↑ Net benefit
Dogliotti et al. [23]; Bartolini et al. [39]	Process-based simulation model Empirical data	Labour	↓ Total labour ↓ Casual labour ↓ Cost
Annetts & Audsley [38]; Dogliotti et al. [23]	Multiple objective linear programming Process-based simulation model	Pesticides	↓ Herbicide use ↓ Losses ↓ Pesticide exposure

Model based land use studies should be used to inform debate on development pathways and get an understanding regarding future agriculture development opportunities [22] to help both the formulation of strategy policy objectives [23], as well as strategic planning by farmers, by using trade-offs between economic and environmental objectives [24 - 29].

As illustrated in Table 1 there exist many different DSSs that focus on different aspects in the agriculture field. The aim of this study, however, is to develop a set of considerations as part of a DSS that can provide assistance to decision makers when they are considering adopting a land use alternative. The DSSs identified in this section focused on a few aspects only, thus not taking the whole farming operation into consideration. Thus, a holistic set of considerations that will evaluate land use alternatives needs to be developed and incorporated into the model.

4. DSS DESIGN

Design requirements and a set of considerations have to be developed and need to be included in the design of the proposed DSS. The purpose of the DSS that was developed in this study can be defined as: to help the decision maker to choose suitable crops in a flexible and user-friendly manner, by allowing the user to provide specified input values to fully explore the relationship between the considerations and the land use alternatives. The design requirements discussed are therefore required to be of such a nature that they will make certain that the aim of the DSS is met as well as ensuring that an accurate reflection of the outputs of the proposed model is provided. According to Rose et al. [13] the following factors are important to ensure successful user acceptance of a DSS: 1) ease of use, 2) performance (the usefulness of the tool and whether it works well), 3) the cost of the DSS, 4) trust (whether or not the tool is evidence based), 5) IT education (whether the tool requires good IT skills to use), and 6) habit (whether the tool relates closely with current farming practices.

The design requirements for the proposed DSS in this specific study, taking the above-mentioned aspects (factors?) into consideration, can thus be stated as follows:

1. The proposed DSS is required to inform the end user which possible land alternatives are viable, given specified input values.
2. The proposed DSS needs to tell the end user which of the alternatives he or she could possibly invest in.
3. Land availability: The proposed DSS should be able to evaluate whether there is enough land available for a particular land use alternative to be viable.
4. Practicality: The proposed DSS should be user-friendly and inexpensive. Furthermore, it should be accessible to a range of different farmers.
5. The proposed DSS should include a combination of viable factors (economic, environmental, labour related, pests/diseases) to evaluate the suitability of a land use alternative for a specified region.
6. The prospective DSS should be flexible, thus addressing the limitation regarding the use of DSSs. It should also be efficient and effective.
7. Trust: the planned DSS should make use of accurate trustworthy data.
8. The risk associated with the different alternatives should be assessed.

Identifying a set of considerations that will give farmers assistance when they are considering any land use alternative type marked the first step in the developing process of the proposed DSS. The set of developed considerations is not just confined to one aspect of the farming operation, such as land suitability or climate suitability, but it rather takes the farming business as a whole into account.

The considerations were identified and established by conducting research about each of the selected land use alternatives. Inputs from subject matter experts have also been used in some cases. Each of the identified considerations, with their accompanying category, are shown in Figure 3.

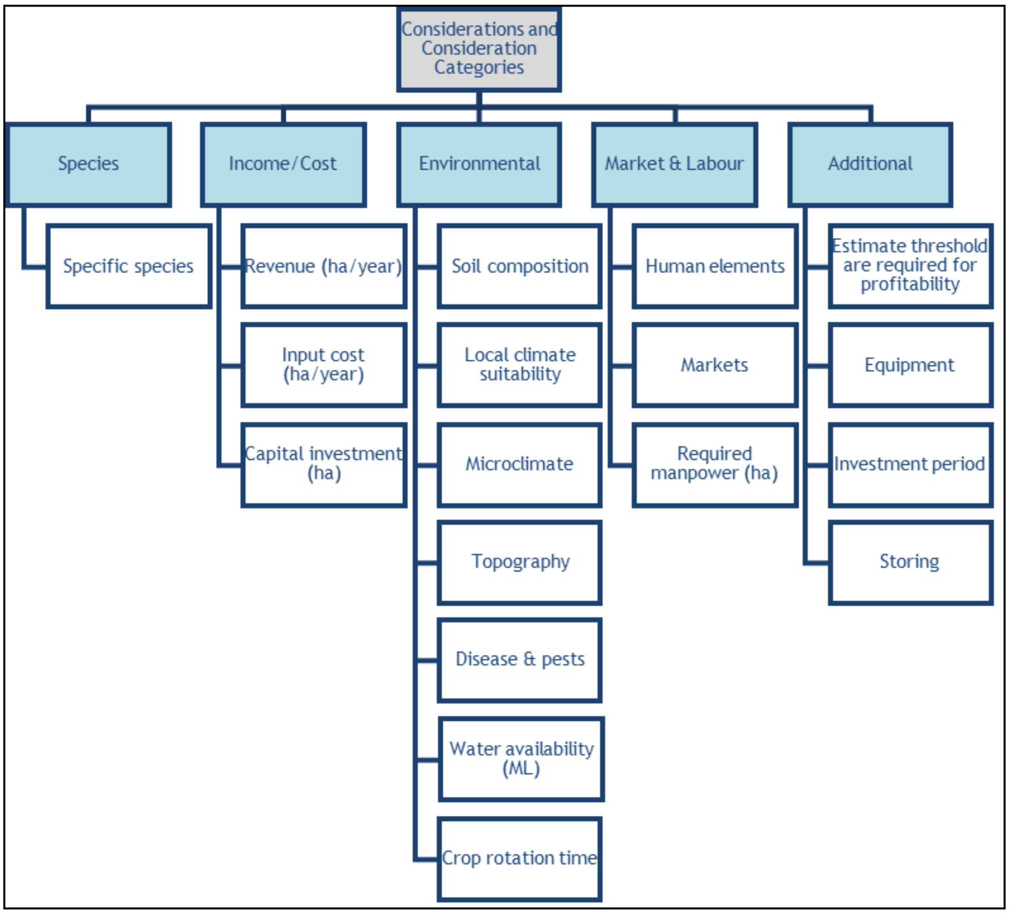


Figure 3: Identified Considerations and main Consideration Categories

The identified considerations play an important part in the feasibility of each of the different land use alternatives and are thus important to examine before implementing any alternative in an intended area. The set of developed considerations that was incorporated into the DSS, are crucial to review before adopting any new land use alternative. Therefore, farm owners should use the DSS as a guide to understand which considerations are important to regard, and subsequently which crops are best suited for their particular region, when they consider adopting a new agriculture diversification strategy.

5. DSS LOGIC

The logic of the DSS provides the reader with an understanding of how the developed DSS works. Process flow diagrams are used to describe the logic of the DSS. Figure 4 provides an overall picture of how the DSS works. It illustrates which information is used and what the DSS accomplishes.

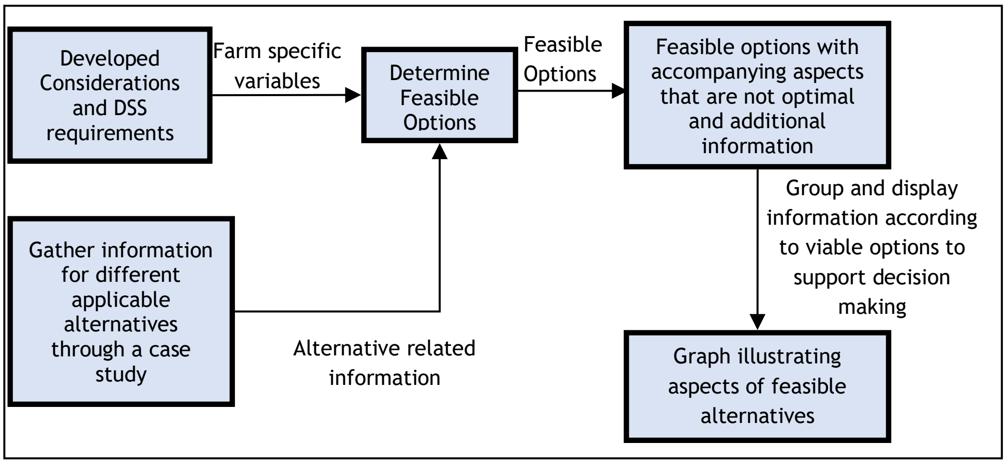


Figure 4: Overall process flow of DSS

Figure 5 shows the process flow of the extended model. The extended model uses the viable options obtained from the DSS as illustrated in Figure 4 together with specified user input. The user can provide the amount of land he or she wants for each of the viable options. Corresponding values of each of the other relative input values are then determined, based on the required provided hectares. A decision maker can thus determine the implications, e.g. cost, for specified hectares, as well as the total of a selected combination of options that he/she wants.

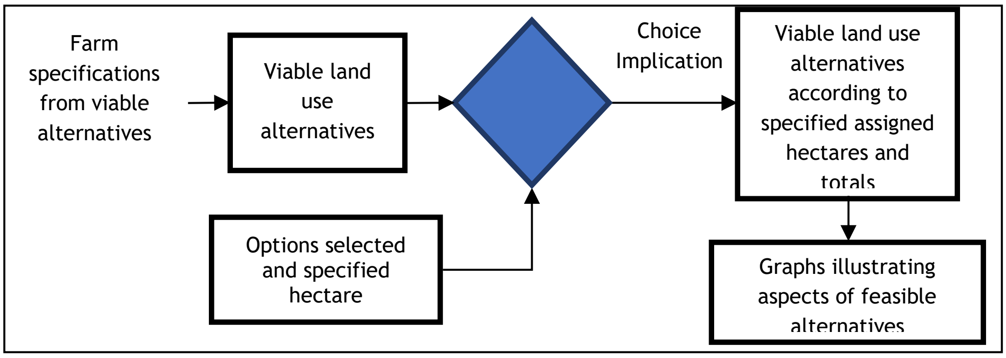


Figure 5: DSS extension process flow

The main purpose of the first developed model is to provide a decision maker viable land-use alternatives that could be adopted according to the user's input data. The information that the researchers gathered to populate the data sheet, together with the set of developed considerations form part of the design of the model. The decision maker is required to provide and fill in data for each of the developed consideration.

The developed DSS and DSS extension makes use of data to provide possible land use alternatives. The purpose of this subsection is to clearly outline the data inputs that the DSS model provides and which data the end user of the model provides.

5.1 Developed DSS data requirements:

The researchers conducted research and held interviews with experts in the agriculture field to populate the data tables that the DSS requires to function. The researchers used a step wise selection process to select a sample of land use alternatives for this study. The research and interviews with experts facilitated populating the data tables for each of the selected land use alternatives. The researchers also provided the annual local sales/exports, annual production, and price data for each of the land use alternatives that were selected for this study. The researchers further developed and provided the set of developed considerations, keys with accompanying meaning, and additional informative information which was included in the DSS. The end user of the DSS has to provide specific user inputs for each of the considerations that are built into the developed DSS. It is important that the decision maker supply this data so that the developed DSS can be tailored to that decision maker's farm/area.

5.2 DSS Extension Data Requirements

The extended model developed in this study, depends on the developed DSS. The model uses the outputs and by implication the data of the DSS. However, the end user is afforded the opportunity to input and compare different hectares allocation scenarios per land use alternative in order to evaluate the expected outcomes of each scenario. After the end user has assigned hectares to each of the alternatives, the DSS extension is programmed to automatically provide the rest of the outputs and generate graphs that are in accordance to the user assigned hectares. The extended model provides the user a choice to manipulate the assigned hectares to evaluate the implication of doing so. For this reason it is important that it is the end user that assigns the hectares to each of the possible displayed land use alternatives and not the DSS.

6. DSS DEVELOPMENT PROCESS

A stepwise process is followed to apply the developed DSS. The process makes sure that the land use options that are selected and intended to be incorporated into the DSS are viable in that specific area. The process steps are shown below and each of the process steps will be executed sequentially.

- Step 1: Identify land use alternatives for the DSS database
- Step 2: Filter Initial land use alternatives for the DSS database
- Step 3: Develop specific considerations for each selected land use alternative
- Step 4: Apply the developed DSS

Figure 6 shows the user interface of the developed DSS with an example of user input values. The input values illustrated are values that a decision-maker chooses, therefore tailored for a specific region. These specified input values are in turn used to provide viable land use alternatives that are applicable in a specific region. The viable land use alternative types which were obtained for the given user inputs of Figure 6, are illustrated in Figure 7. Each of the illistrated land use alternatives shown in Figure 7 are viable according to the tailored values of Figure 6. Thus, for the example input data shown in Figure 6, mandarins, cling peaches, or cabbage are shown as viable options in Figure 7. According to the developed DSS a decision-maker can choose any one of the abovementioned three alternatives for their specific region.

Considerations	User Input
Total budget in first year	R 9 000 000.00
Average min temp of coldest month (°C)	3
Available Infruitec Chilling units (hours)	20
Water Availability (ML/Year)	9000
Human Element	1
Hectares available	20
Manpower available	70
Equipment	1
Rainfall Season Region	0
Production stability	0
Packing storage available on own premises (or access to one)	1
Cellar available on own premises	0
Soil Composition-pH level (average)	5
Local Climate Suitability-Rain (average)(mm)	600
Average annual temperature (Lower bound)(°C)	15
Average annual temperature (Upper bound)(°C)	25
Sales stability	1
Price stability	1

KEY

Human Element: Keys	
Low Skilled Staff	1
Medium Skilled Staff	2
High Skilled Staff	3

Equipment: Keys	
No equipment, manpower only	1
20% equipment, 80% manpower	2
40% equipment, 60% manpower	3
50% equipment, 50% manpower	4
60% equipment, 40% manpower	5
80% equipment, 20% manpower	6
100% equipment, no manpower	7

Availability: storage, cellar	
Yes	1
No	0

Rainfall season	
Winter	1
Summer	2

Production Stability	
Stable required	1
No preference	2

Sales Stability	
Stable required	1
No preference	2

Price Stability	
Stable required	1
Moderately stable	2
No preferance	3

Clear options

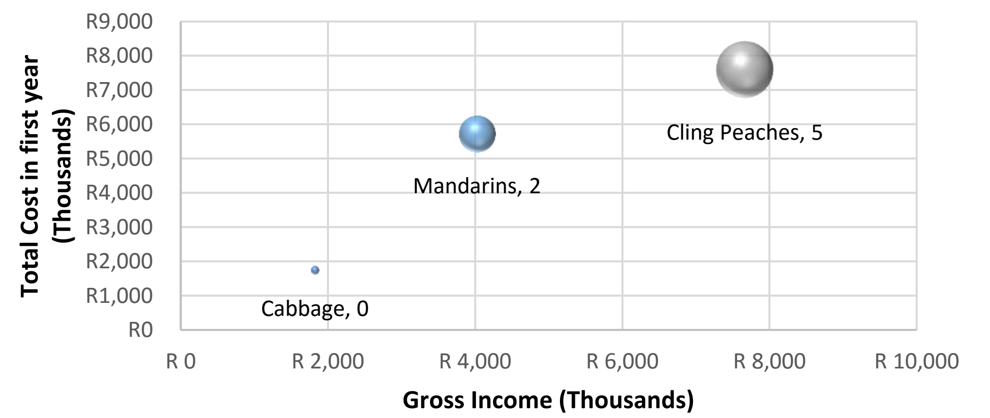
Determine viable options

Figure 6: Considerations where user gives an input (left) accompanying user input keys (right)

The viable land use alternatives generated according to the user input of Figure 6 are used to create a graph (Figure 8) which compares the total cost in the first year with the expected gross income per viable option.

VIABLE LAND-USE ALTERNATIVES			
Land-use alternative	**Mandarins**	**Cling Peaches**	**Cabbage**
Annual Gross Income (Based on hectars required)	**R 4 024 725.00**	**R 7 666 666.00**	**R 1 822 485.20**
Capital Investment in first year (Based on hectars required)	R 2 799 750.00	R 2 365 160.00	R 1 300 000.00
Input Cost per year (Based on hectars required)	R 2 923 680.00	R 5 224 320.00	R 451 434.20
Total Cost in first year (Based on hectars required)	**R 5 723 430.00**	**R 7 589 480.00**	**R 1 751 434.20**
Remaining budget	R 3 276 570.00	R 1 410 520.00	R 7 248 565.80
Hectares required	15	20	20
Hectares remaining	5	0	0
Investment Period	2	5	0
Harvest month (start)	4	11	9
Crop rotation time (if required)			3
Risks	Markets regulation changes Change of overseas protocalls and regulations New diseases, specifically Asian Greening Labour related risks	Very sensitive to climate changes, tree develops buttons if not adequate amount of Infruitec chilling Pests/Disease Filed fire if orchard are not kept clean	Pests Plague Weed Hail Market establishment
Known diseases/fungi	Alternaria brown spot Fusarium (secondary fungus) Phytophthora parasitica	Bud mite	Alternaria leaf spot
Known pests	Red scale South African citrus thrips Mediterranean fruit flies Budworm Woolly whitefly	American budworm Snout Beetle	Diamond back moth Cutworm Thrips American bollworm Grey cabbage aphid
Unfavourable conditions	Human Element Equipment Sales stability Price stability Average annual temperature (Lower bound)(°C)	Equipment Sales stability Average annual temperature (Lower bound)(°C) Available Infruitec Chilling units (hours) Rainfall Season Region	Price stability Average annual temperature (Lower bound)(°C) Rainfall Season Region Local Climate Suitability-Rain (average)(mm) Average annual temperature (Upper bound)(°C)
Harvest length (months)	2.5	1	1

Figure 7: Output with provided user input of Figure 6



*Bubble sizes represent investment

Figure 8: Cost in first year vs annual gross income relation for user input of Figure 6

Furthermore, the sizes of the bubbles in the depicted graph shows the investment period that is required before an alternative is expected to generate income. Figure 9 shows the extended DSS model, which uses the generated viable alternatives of the DSS model together with the user input of Figure 6. The values generated for each of the considerations as depicted in Figure 9 depends on the number of assigned hectares, in this case 20, 15, and 10 hectares that were assigned to mandarins cling peaches, and cabbage respectively. The totals thus reflect the total combined amounts of the different viable options when 20, 15, and 10 hectares are assigned to the respective viable alternatives. Figure 9 show this combination of alternatives with the assigned hectares exceeding the specified budget. The values for different input values and outputs generated can be graphically shown to facilitate visible analysis while using the DSS. Consequently, the farmer can for example phase the combined hectares in over several years, or if (s)he likes, adjust his/her initial amount of input hectares

Considerations	VIABLE LAND USE ALTERNATIVES		
Land-use alternative	Mandarins	Cling Peaches	Cabbage
Hectares Assigned	20	15	10
Hectares Remaining	70	75	80
Annual Gross Income	R 5 366 300.00	R 5 749 999.50	R 911 242.60
Capital Investment in first year	R 3 733 000.00	R 1 773 870.00	R 650 000.00
Input Cost per year	R 3 898 240.00	R 3 918 240.00	R 225 717.10
Total Cost in first year	R 7 631 240.00	R 5 692 110.00	R 875 717.10
Remaining budget	R 1 368 760.00	R 3 307 890.00	R 8 124 282.90
Manpower required	21	19.5	15
Manpower remaining	49	50.5	55
Water required (ML/year)	153	135	0.045
Water remaining (ML/year)	8847	8865	8999.955
	TOTALS		
Hectares Assigned	45 ha		
Hectares Remaining	45 ha		
Annual Gross Income	R 12 027 542.10		
Capital Investment in first year	R 6 156 870.00		
Input Cost per year	R 8 042 197.10		
Total Cost in first year	R 14 199 067.10		
Remaining budget	Insufficient funds. Additional R 5199067.1 required		
Manpower required	56 workers		
Manpower remaining	14 workers		
Water required (ML/year)	288 ML/year		
Water remaining (ML/year)	8712 ML/year		

Figure 9: Populated extended DSS model according to user input of

Figure 6

One example of this is show in Figure 10 to quickly compare how much of the available resources each of the viable options use. This is used to evaluate different considerations of the viable options according to the assigned hectares, compares the percentage contribution of the total amount for manpower,water used, input cost, and capital investment in the first per alternative. If an equal amount of hectares is assigned to each of the viable alternatives, Figure 10 can be used to compare the viable alternatives with each other per indicated considerations.

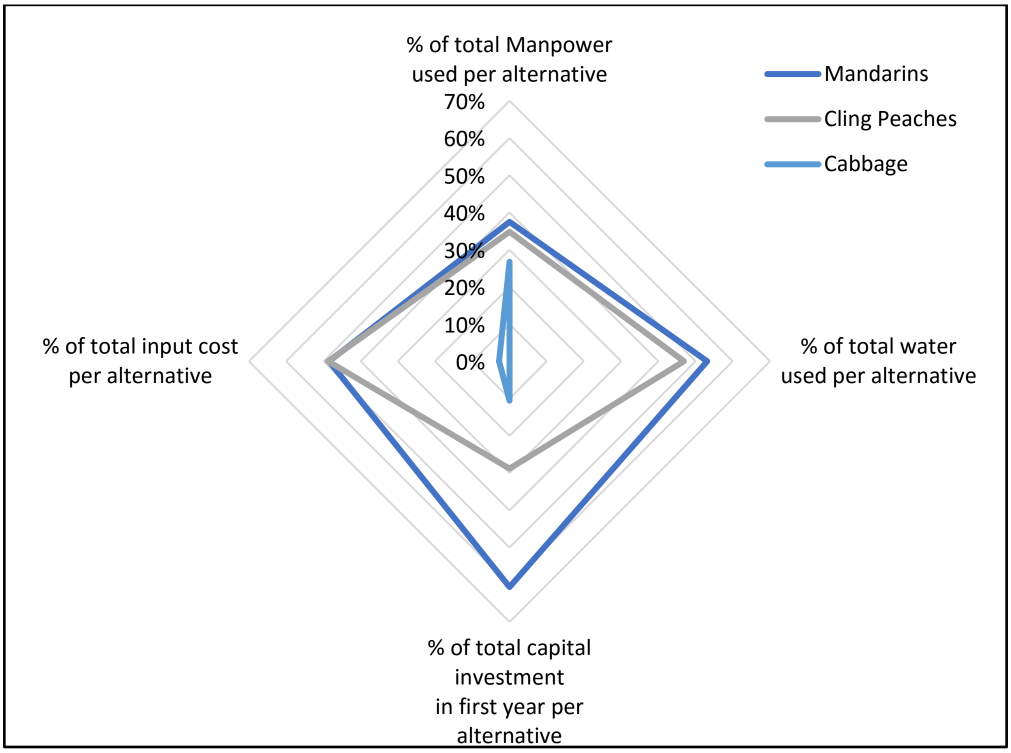


Figure 10: Percentage of available resources used per alternative considered

7. VALIDATION

Junier & Mostert [15] refer to validity as a model's capability to portray reality accurately. Information should therefore be seen as useful. Thus, it should be fit for the purpose, accessible, and user-friendly. The information therefore, is required to be perceived as valid in turn. Additionally, the perceived validity of a model or a DSS is determined by those who work with it, both the developers and the users [14]. Validating something therefore, gives credibility to a claim or statement. Therefore, it is important to validate one's work, to incorporate credibility and quality into it. The purpose of this section is to validate the developed considerations and resulting developed DSS. An internal validation was done after which subject matter experts were consulted to be able to conduct an external validation.

7.1 Internal Validation

To apply this step, an internal validation was conducted by the research team to determine whether the developed DSS provides the expected outputs. For these scenarios the team provided different input values. Logic and extreme conditions tests were done by the researchers to test the DSS model's capabilities to function within the boundaries of resources avaialable and to test the input limitations that could be provided by the end user.

7.2 External Validation

The set of considerations developed was used for validation purposes. The researchers developed the considerations using inputs from experts and research to determine what is important and needs to be taken into account when a decision maker considers undertaking a new land use alternative. Experts were approached to test the DSS model's input parameters and to validate the outputs generated. The experts applied the DSS to their own unique farm environment and found it to be informative and helpful. A number of suggestions and comments on the grpahic user interface was considered and implemented.

8. CONCLUSION AND RECOMMENDATIONS

The literature analysis placed emphases on strategic decisions for landscape alternatives and indicated land use alternative decisions as strategic decisions. The literature suggested that diversification strategies offer a trajectory toward viability, because income is generated from multiple sources which can account for business cycle variations and variation of seasonal income. In this study, diversification was primarily considered as agriculture diversification that is engaged in the cultivation of various crops. This definition excludes farm strategies aiming to relocate and recombine farm resources away from their original farming activities to generate an additional form of non-agricultural income.

Literature further suggested that existing DSSs only focussed on certain aspects regarding the suitability of an agricultural crop, thus not considering the whole farming operation when deciding which crops to select. The aim of the model developed in this study was to develop a holistic set of considerations that will evaluate land use alternatives and which would be incorporated into the model. These considerations are crucial to review before adopting any new land use alternative. Therefore, farm owners should use the DSS as a guide to understand which considerations are important to regard, and subsequently which crops are best suited for their particular region, when they consider adopting a new agriculture diversification strategy.

It is recommended that bankers can greatly benefit in using the developed DSS as a risk management strategy to inform farmers which agriculture strategy would be best to follow when farmers approach a bank for an agriculture loan. The researchers suggests that the best method to populate complete input crop datasets, would be to appoint agricultural consultants and agencies to collect significant amounts of data on their field of expertise. Agricultural consultants and bankers can then use this pool of data with the DSS model, to assess risks and advise farmers. Agricultural consultants and agencies can be used to keep the data pool updated for their crop alternatives.

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